# PERFORMANCE OF SOLID MATERIAL DIVERTER SUBJECT TO IMPACT COLLISION WITH RESPECT TO ANGLE VARIATION

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## DEDICATION

*Specially for my beloved wife, parents,*

*brothers, sister and friends*

*Who has a chamber in my heart...*

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# ABSTRACT

Sustainable Hydrokinetic Renewal Energy Power Generation System (SHRE) is an energy harvesting system that operates in the river of Sarawak and subjected to impact of floating debris. In order to resist the impacts from floating debris, the Solid Material Diverter (SOLMAD) is proposed for the protection of SHRE system. Floating debris in the river, normally timber logs, could damage the SOLMAD and misalign the turbine orientation, which in return could reduce the lifespan and efficiency of the hydrokinetic turbine to harness energy. This research aims to model SOLMAD of various angles that are subjected to impact loading induced by floating debris. Five angle variations, namely 15°, 30°, 45°, 60°, and 75° were taken into consideration for analysis and design of the SOLMAD. The size of timber logs, river profile, and flow velocity were obtained from site sampling data collection at the Balleh River, Sarawak. The mass from the recorded sampling of floating debris and velocity of the river were then converted into equivalent impact forces on the SOLMAD structure using the Work-Energy method. Scaled down models were investigated experimentally in the laboratory to investigate their stability and validate the theoretical impact forces calculated using the Work-Energy method. A total of five models were developed with 3-dimensional line elements using the STAAD.Pro software. The models were analysed under the most critical load cases using the calculated equivalent impact forces to obtain the internal forces and displacements. The models were then designed with optimised steel section using Eurocode 3. The study showed that structural orientation of 15° and 30° performed better in terms of stability and float ability on the water compared to the other angle orientations. From the structural design standpoint, by using Eurocode 3, angle section of 100 mm x 100 mm x 12 mm and 150 mm x 150 mm x 12 mm were adopted as the most optimum sections to design the SOLMAD. Based on the overall performance of structural stability in water and structure self-weight, the selection of 30° model was proposed as the SOLMAD structure.

# ABSTRAK

Sistem Penjanaan Kuasa Tenaga Hidrokinetik Boleh Diperbaharui (SHRE) adalah sistem penuaian tenaga yang beroperasi di sungai Sarawak dan mengalami perlanggaran dengan bendasing terapung. Untuk mengatasi kesan dari bendasing terapung, Penyisih Bendasing (SOLMAD) dicadangkan untuk melindungi sistem SHRE. Bendasing terapung di sungai, biasanya kayu balak, boleh merosakkan SOLMAD dan mengubah orientasi turbin, yang mana boleh mengurangkan jangka hayat dan kecekapan turbin hidrokinetik untuk penuaian tenaga. . Kajian ini bertujuan untuk mengkaji model SOLMAD dengan variasi sudut perlanggaran oleh bendasing terapung. Variasi lima sudut, iaitu 15°, 30°, 45°, 60° dan 75° diambil kira untuk tujuan analisis dan reka bentuk SOLMAD. Saiz kayu balak, profil sungai, dan halaju aliran diperoleh dari pengumpulan data pengambilan tapak di Sungai Balleh, Sarawak. Ketumpatan sampel bendasing terapung yang direkodkan dan halaju sungai kemudian diubah menjadi daya impak setara pada struktur SOLMAD menggunakan kaedah Tenaga-Kerja. Model berskala kecil dikaji secara eksperimen di makmal untuk dikaji kestabilan dan validasi pengiraan daya impak secara teori menggunakan kaedah Tenaga Kerja. Sejumlah lima model telah dibangunkan dengan unsur garisan 3 dimensi menggunakan perisian STAAD.Pro. Model-model ini dianalisis di bawah beban kes yang paling kritikal dengan menggunakan daya impak setara yang dikira untuk mendapatkan daya dalaman dan daya anjakan. Model-model keluli ini direkabentuk secara optimum menggunakan Eurocode 3. Kajian menunjukkan struktur berorientasi 15° dan 30° lebih baik dari segi kestabilan dan keupayaan untuk terapung di atas air berbanding sudut yang lain. Dari sudut rekabentuk struktur, dengan menggunakan Eurocode 3, keluli bersudut 100 mm x 100 mm x 12 mm dan 150 mm x 150 mm x 12 mm telah digunakan sebagai bahagian paling optimum untuk rekabentuk SOLMAD. Berdasarkan prestasi keseluruhan dari segi kestabilan struktur dalam air dan struktur berat sendiri, pemilihan model 30° dicadangkan sebagai struktur SOLMAD.

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## SYMBOLS:

| | | |
|---|---|---|
| $\lambda$ | - | Slenderness ratio |
| $\delta$ | - | Deflection |
| $\varepsilon$ | - | Strain or constant in classification of a section |
| $\lambda_{LT}$ | - | Equivalent slenderness ratio |
| $A$ | - | Cross sectional area |
| B | - | Breadth of structure |
| $D$ | - | Depth of section |
| $DWT$ | - | Dead Weight Tonne (US Tonne) |
| $E$ | - | Young's modulus (205000 N/mm$^2$) |
| $Fi_{max}$ | - | Maximum force |
| $F_{v(kips)}$ | - | Maximum force (kips) |
| $F_x$ | - | Critical Force |
| H | - | Height of submerged structure |
| KE | - | Kinetic energy |
| KM | - | Keel to metacentre distance |
| KB | - | Center of Buoyancy |
| $m_1$ | - | Mass of log |
| $M_{cy}$ | - | Moment capacity of section in major axis |
| $M_{cz}$ | - | Moment capacity of section in minor axis |
| $M_y$ | - | Applied end moment about the major axis |
| $M_z$ | - | Applied end moment about the minor axis |
| $N_{b.Rd}$ | - | Buckling resistance |
| $P$ | - | Concentrated load |
| $p_c$ | - | Compression resistance |

| | | |
|---|---|---|
| $p_{cy}$ | - | Compression resistance on minor axis |
| $P_u$ | - | Ultimate axial load |
| $p_y$ | - | Design yield strength |
| $p_v$ | - | Vertical shear force resistance |
| $R_p$ | - | Yield strength |
| $R_m$ | - | Tensile strength |
| S | - | Stopping distance |
| $S_x$ | - | Plastic modulus about the major axis |
| $S_y$ | - | Plastic modulus about the minor axis |
| $\mathrm{t_i}$ | - | Time of initial contact |
| $V$ | - | Shear force in beam |
| V | - | Volume of displacement |
| $Z_x$ | - | Elastic section modulus about the major axis |
| $Z_y$ | - | Elastic section modulus about the minor axis |

**NOTATION:**

| | | |
|---|---|---|
| P0 | - | Location for maximum impact force exerted to most front member of SOLMAD |
| P1 | - | Location no. 1 for maximum impact force exerted to SOLMAD Wall |
| P2 | - | Location no. 2 for maximum impact force exerted to SOLMAD Wall |
| P3 | - | Location no. 3 for maximum impact force exerted to SOLMAD Wall |
| P4 | - | Location no. 4 for maximum impact force exerted to SOLMAD Wall |
| P5 | - | Location no. 5 for maximum impact force exerted to SOLMAD Wall |
| P6 | - | Location no. 6 for maximum impact force exerted to SOLMAD Wall |

| | | |
|---|---|---|
| P7 | - | Location no. 7 for maximum impact force exerted to SOLMAD Wall |
| P8 | - | Location no. 8 for maximum impact force exerted to SOLMAD Wall |
| P9 | - | Location no. 9 for maximum impact force exerted to SOLMAD Wall |
| P10 | - | Location no. 10 for maximum impact force exerted to SOLMAD Wall |
| P11 | - | Location no. 11 for maximum impact force exerted to SOLMAD Wall |
| P12 | - | Location no. 12 for maximum impact force exerted to SOLMAD Wall |
| P13 | - | Location no. 13 for maximum impact force exerted to SOLMAD Wall |
| P14 | - | Location no. 14 for maximum impact force exerted to SOLMAD Wall |
| P15 | - | Location no. 15 for maximum impact force exerted to SOLMAD Wall |
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| P17 | - | Location no. 17 for maximum impact force exerted to SOLMAD Wall |
| P18 | - | Location no. 18 for maximum impact force exerted to SOLMAD Wall |
| P19 | - | Location no. 19 for maximum impact force exerted to SOLMAD Wall |
| P20 | - | Location no. 20 for maximum impact force exerted to SOLMAD Wall |
| P21 | - | Location no. 21 for maximum impact force exerted to SOLMAD Wall |
| P22 | - | Location no. 22 for maximum impact force exerted to SOLMAD Wall |
| P23 | - | Location no. 23 for maximum impact force exerted |

| | | |
|---|---|---|
| | | to SOLMAD Wall |
| P24 | - | Location no. 24 for maximum impact force exerted to SOLMAD Wall |
| P25 | - | Location no. 25 for maximum impact force exerted to SOLMAD Wall |
| P26 | - | Location no. 26 for maximum impact force exerted to SOLMAD Wall |
| P27 | - | Location no. 27 for maximum impact force exerted to SOLMAD Wall |
| P28 | - | Location no. 28 for maximum impact force exerted to SOLMAD Wall |
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| P36 | - | Location no. 36 for maximum impact force exerted to SOLMAD Wall |
| P37 | - | Location no. 37 for maximum impact force exerted to SOLMAD Wall |
| P38 | - | Location no. 38 for maximum impact force exerted to SOLMAD Wall |

**ABBREVIATIONS:**

| | | |
|---|---|---|
| ASTM | - | American Society For Testing and Materials |
| BS 5950 | - | British Standard 5950 |
| BSI | - | British Standard Institution |
| DWT | - | Deadweight Tonne |
| EC 3 | - | Eurocode 3 |
| UA | - | Universal Angle section |
| ULS | - | Ultimate Limit State |
| SLS | - | Serviceability Limit State |
| LL | - | Live load |
| DL | - | Dead load |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 General

Solid material diverter (SOLMAD) is a system introduced to the JKR-UTM-UPM sustainable hydrokinetic renewal energy (SHRE) turbine system in order to endure turbine steadiness by diverting any moving solid materials through the river currents from impairing the turbine system (Figure 1.1). The SOLMAD system is one of eleven systems or projects that need to be developed in order to form a complete hydrokinetic turbine system that can function in the river as shown in Table 1.1. SHRE turbine system is one of the models that will produce electricity from hydrokinetic energy of the river flow. The pilot project for this turbine system was carried out in one of the rivers in the state of Sarawak. The content of the regulation of the local authorities of Sarawak restricts any construction of fixed structures in the river; therefore, a floating solid debris diverter structure has to be built.

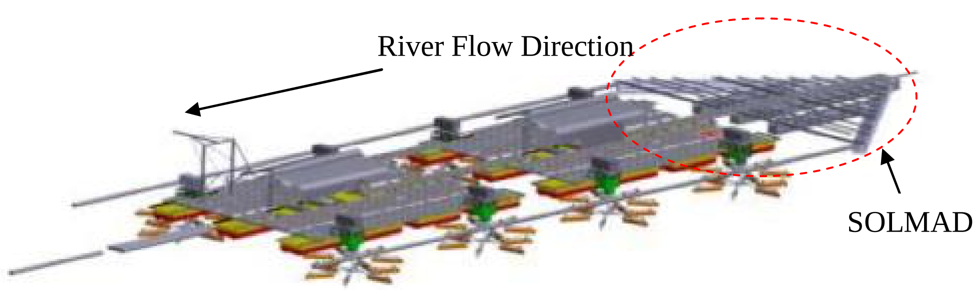


**Figure 1.1** Schematic of JKR-UTM-UPM Sustainable Hydrokinetic Renewal Energy Turbine System Sketch

**Table 1.1:** JKR-UTM-UPM SHRE Sub Project/Systems

| **No.** | **SHRE-SubProject** |
|---|---|
| 1. | Modular Floating Pontoon System (MFLOPS) - |
| 2. | Hydrokinetic Turbine Energy Transmission System (HTETS)- |
| 3. | Hydrokinetic Energy Transformation System (HETS)- |
| 4. | Hydrokinetic Turbine Anchoring System (HTAS) |
| 5. | Solid Material Diverter (SOLMAD) |
| 6. | Intelligent Hydrokinetic Control & Monitoring System (iHCMS) |
| 7. | Hydrokinetic Turbine Operational Control System (HTOCS) |
| 8. | Integrated Green Energy Profiler  Enviromental Logger (iGEPEL) |
| 9. | Hydrokinetic Crude Energy Stabilizer (HCES) |
| 10. | Hydrokinetic Power and Control Protection System (HPCPS) |
| 11. | Hydrokinetic Green Energy Converter (HGEC) |

## 1.2 Research Background

SOLMAD consists of floaters that cover the frame structure (main structure) and grating as the structure deck as shown in Figure 1.2. The floaters use UPVC end capped material while the grating is galvanised iron and the main structure uses angle iron with a variety of sizes. The joints of the frame structure are joined together using bolts and nuts. The SOLMAD structure, which will be operating on the surface of the river, will be anchored to the bottom of the river using a concrete block. It also functions as an anchor for the turbine pontoon structure which is attached to the back of the structure. The structure is designed to be modular due to mobility reason as the location restricts in using machineries plant.

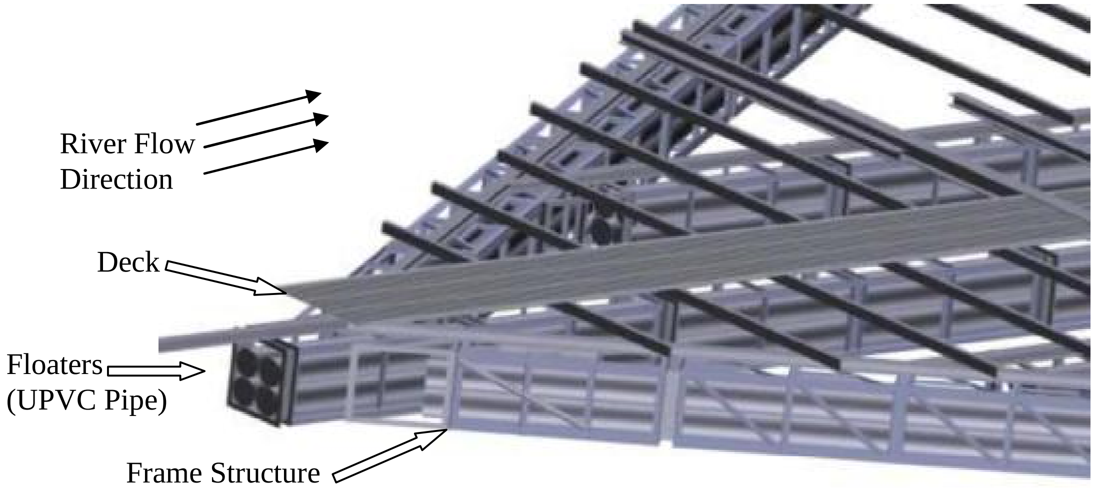


**Figure 1.2** The floaters (UPVC pipe) were slot in through the frame structure to create buoyancy to SOLMAD

The characteristic of a large solid material poses a much greater risk to the structure, turbine blade, and platform fitness since the impact momentum is quite high. Large debris most commonly enters the flow either during a flood event or because of bank erosion (Bradley et al., 2005).The magnitude of the forces can be large enough to cause substantial or even catastrophic damage to the structure (Haehnel & Daly, 2002a). The probability of the platform that supports the turbine system to be misaligned due to an impact will significantly reduce the efficiency of the blade in harnessing kinetic energy from the river current. In the river, it is impossible to avoid any contact between the turbine system structure and solid debris that flows along the river. Hence, the best solution to this problem is to minimise the impact stress induced during the collision by using a structure to divert the debris away from the blade turbine. During the divert process, a structure will experience the collision impact between the solid material and the diverter itself, where the surface of the contacted structure will tend to have an increase in deformation and stress induced. This event could be critical if the selection of optimum angle diversion and stress analysis study are not taken into consideration cautiously as they would make the structure functions at its optimum stage. Impact orientation could be in the range of 1° to 90° according to the position of impact wall and logs alignment during collision. The behaviour of the impact could induce certain stress at the impacted wall, which will reduce the lifespan of the SOLMAD system that was initially designed to be sustainable with effective life cycle cost. The impact wall is the structure that has direct contact with the solid material. It must be able to perform its diverting function with a permissible stress occurrence. The selection of the angle of impact from 1° to 90° in variation is crucial to ensure that the turbine could sustain for a longer period of time in the river.

## 1.3 Research Problem

The diverting event would certainly induce stress during the impact between the debris and the wall of the diverter. Therefore, management of stress is necessary to minimise the amount of stress induced. For that reason, by changing the angle of the wall, the impact orientation will be changed as it reduces the stress induced, because the stress will increase the durability of the SOLMAD structure. Wooden log position varies when it is streaming in the river. The stress amount of log impact could vary due to the orientation (angle) of the log that is moving through the water. Stress analysis on the impact wall is one of the imperative elements to particularly study the stress by the angle of impact. Since the angle orientation of the log is practically impossible to control, the angle of diverter could be changed to lower the amount of stress by the angle of impact of the wall structure. By using experimental laboratory impact test and STAADPro design analysis software, the study of impacted wall can be done comparatively. In this study, the most optimum angle of the structure wall to receive the impact stress was determined, hence, the system was able to improve its stiffness during the diverting event.

## 1.4 Research Objectives

The objectives of this study are as follows:

a) To investigate the effect of angle variations to the design of SOLMAD through finite element modeling.

b) To conduct economic comparisons in terms of savings steel weight for SOLMAD at different angles.

## 1.5 Research Scope

The scopes of this research covered analytical, parametric, and laboratory experiment studies. The parametric and analytical studies emphasised on the analysis of impact by finite element method and the analytical of results, while the experimental study validated and justified the simulation of finite element method as follows:

i. The paper covered the study of stress analysis that occurred by impact collision between the SOLMAD structure with the solid material (woody debris).

ii. The angle of wall will be varies to several angle (15°,30°,45°,60°,75°). The 5 angles of orientation which has been selected which is assume to be adequate. For further study, the exact optimum wall impact can be done in the future.

iii. The ability of the SOLMAD to float on the river was made possible by the introduction of floaters. The SHRE Project decided to use 300 mm diameter UPVC pipes with end capped as floaters.

iv. The stability of SOLMAD was determined by the metacentre determination and stability test. The consideration of metacentre was applied during the regular river current flow since hydrodynamic effects such as wave was covered in this study. The stability test consisted of five scale models with variations of impact angle (15°,30°,45°,60°,75°) tested in a laboratory flume at the National Hydraulic Research Institute of Malaysia (NAHRIM) located in Serdang.

v. Since the profile of the river varied due to the bed condition, which determined the vorticity of the flow and movement of the log, the research considered the condition where the log moved straight by following the river current.

vi. The types of debris included in the study were solid wood trees due to their solid mass debris and most frequent flow in the river. This research assumed the study of diverting large wooden logs to be the biggest challenge in handling debris in the specific river and all small solid materials were also considered to be diverted by this structure.

vii. The testing simulation neglected the hydro dynamics effect on the wall even though it can reduce the amount of stress. The study only considered the genuine impact regardless of the hydrodynamic effect and movement ability of the actual structure in the river because the effect of water was secondary compared to the "pure" structural impact, thus, it can likely be neglected for the design.

viii. The study also covered structure element of the impacted collision that occurred first. The determination at the hit point considered the highest in stress but the overall structural integrity was also considered by the analysis.

ix. Laboratory test was conducted to verify the selection of the impact forces' equations. The test was conducted in a flume since the scale model was acceptable by assuming it as a simplified dynamic model and it was used to provide an accurate estimation of the impact demands (Piran et al. 2014). Since impact collision force was considered greater than water viscosity, which was 0.001 Pa.s (Pascal-second), kg/m/s, the backwater condition can be neglected.

x. The finite element method associated by using STAADPro software that applied the maximum impact force calculated before was used in this study.

xi. The self-weight determination of the five models with the variations of angle was based on the weight of the SOLMAD structure designed using the STAADPro software.

## 1.6 Significance of Research

Optimum design of the SOLMAD system should be economical, light, and good in mobility during installation on site later. The research application could help designers of any floating structures on rivers, especially in the remote areas of Sarawak because data acquisition for this study was done in a remote area in Kapit, Sarawak, Malaysia.

## 1.7 Structure of Thesis

This thesis consists of five chapters. Chapter 1 explains the background, objectives, and scope of the study. Chapter 2 reviews the previous studies on diverter, preliminary design concept of SOLMAD, material and component selection, stability of a floating structure, impact test, and wooden debris. Chapter 3 will explain the research methodology. This chapter covered the detail frame design of SOLMAD, theoretical part of the metacentre and determination of the centre of buoyancy, and theoretical stability test and impact done in the laboratory. Chapter 3 will also cover the methodology of the SOLMAD structure including stability, buoyancy, impact force analysis, design section, and data collection. On the other hand, Chapter 4 covers the stability of the SOLMAD which included the stability test and determination of metacentre calculations, a collection of river velocity and profile, a collection of log data, and theoretical prediction of maximum impact force. The laboratory impact test was executed in a flume while the validation of the theoretical impact forces was made based on the laboratory impact force data. The log data and river profile collection on site were also elaborated in this chapter. Other than that, this chapter will also present the analysis of the SOLMAD structure, design section properties, and overall weight of the structure with a comparison to the proposed angle models. The selection of the SOLMAD impact forces was explained in the final topic of this chapter. Last but not least, Chapter 5 will determine the conclusion and recommendation for further studies.

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